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ScienceDirect

Energy Procedia 45 (2014) 308 – 314

Energy Procedia

68th Conference of the Italian Thermal Machines Engineering Association, ATI2013

Experimental analysis of PVT panels for industrial applications

Giampietro Fabbri[1], Matteo Greppi[2]*

[1]D.I.N. ,Università degli Studi di Bologna,Viale Risorgimento 2, 40136 Bologna, Italy
[2]D.I.N. Università degli Studi di Bologna ,via Fontanelle 40, 47121 Forlì

Abstract

The proposed work involves the study and optimization through numerical and experimental analysis of a hybrid thermophotovoltaic panel for industrial applications. Starting from the numerical optimization of the profile of the heat sink obtained by genetic algorithms and taking into account the physical constraints and constructive problems, the aim is to develop and analyze new hybrid prototypes specifically designed . The prototype built always presents, as energy result , the combined thermal and electrical outputs but is designed to ensure the integration of construction, mechanical properties and specific functional requirements requested by industrial applications.

Keywords: hybrid, thermophotovoltaic, industrial , efficiency.

1.Introduction

The ever increasing need for rationalization of energy use provides a significant increase in the number and size of production systems.A possible solution for that increasing need is the local production of electricity and heat, and this also in order to lighten the load of distribution networks, now often subjected to excessive stress conditions. The advantages are many, such as the elimination of costly transport infrastructure, energy transformation and distribution.The use of decentrated local power plants (certainly small compared to large power plants) and the expansion of renewable energy are two necessary devices to reach this goal .In order to achieve better these objectives, the hybrid renewable PVT (thermophotovoltaic) allows the direct transformation of solar radiation into electricity and the production of solar thermal energy on the same surface. The environmental benefits obtainable from the adoption of PVT panels are proportional to the amount of energy produced, assuming that this is going to replace the energy supplied by conventional sources. In add of this the heat and power cogeneration increases the overall efficiency of energy production.Based on the results obtained in previous research literature, our work has been focused to realize a finite volume model with fixed parameters using genetic algorithms in order to identify the geometry of the heat exchange system that allow the best performance for our specific applications .
Subsequently has been prototyped the hybrid panel (Fig.1) for the tests and measurements of heat and electricity

Selection and peer-review under responsibility of ATI NAZIONALE
doi:10.1016/j.egypro.2014.01.033

available to be carried out in different conditions of solar radiation and atmospheric temperature.
From the experimental analysis the aim is also to deduce an accurate optimization strategy for the design and the guidelines on the sizing of that technology production system and its specific use. The aim is to abtain all the advantages of this modular solution for little size boat systems (for example sailing boat less than 10 kW).In a final stage the results obtained on the prototype will be compared with the predictions of numerical models. If necessary it will be arranged to alter designs for new prototypes.

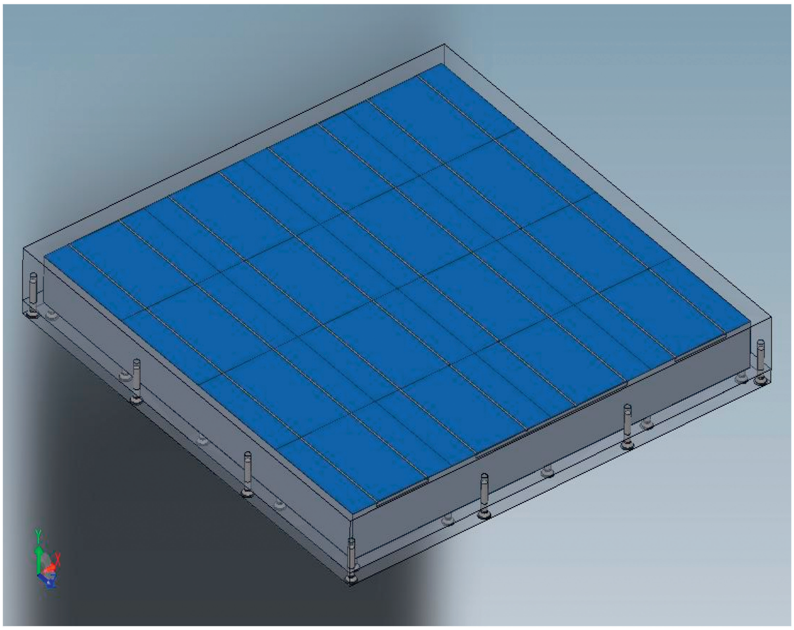


Fig.1. Hybrid Industrial Prototype

2. Experimental apparatus

The hybrid prototype (PVT) is made of : an aluminium heat sink optimized by genetic algorithms developed by Matlab; PV high efficiency monocrystalline cells soldered together and mechanically connected thanks to a thermally conductive silicon paste to ensure a satisfactory thermal contact between the heat sink and the solar cell panel; a covering case made of Plexifluid (liquid plexiglass) by Prochima with cold resin polymerization and the bottom plexiglass enclosure (plexiglass choice is based on its good mechanical and optical properties).The bottom one is mechanically connected watertight with M5 screws to the picture frame of the heat sink.Two circular holes (inlet and outlet) permit the fluid to flow and collect thermal energy then stored in the hydraulic circuit.The others panel structures built for panel comparison are the photovoltaic one (PV) and the solar thermal one (ST).
The hydraulic system circuit (Fig.2) consists of : a fluid flow circulator (adjustable with three variable velocity), hoses of Rilsan, a thermostatic water bath, a flow meter that detects the flow rate working towards the hybrid and solar panel and a needle valve to adjust the hydraulic resistance of the solar panel on the branch. As a coolant water is employed.T-type thermocouples with a measurement range between -200°C to + 400°C (uncertainty is +/-1°C or +/- 0.75%) provide temperature values and a pyranometer measures the global incident radiation .In our mobile plant layout above described consisting of the three different panel structures(PV, ST, and PVT) the liquid exiting

* Corresponding author. *E-mail address*: matteo.greppi2@unibo.it

the plates is cooled in the thermostatic water bath and returned through pumping to the cold plates' inlet, at a fixed temperature .The values analyzed for fluid flow rate are 0.000018, 0.00003 and 0.0000425 m^3/s.
The T-type thermocouples were connected to a digital data acquisition interface, which also measures the frequency signal from a flow meter to determine the mass flow rate in the loop. A dedicated LabView interface has been created to easily collect and process the measured data. This device has a measurement range between 0 and 1999 W/m2°C with an uncertainty of +/- 10 W/m^2.The global irradiation G incident on the inclined surface (33°) derived from pyranometer values is also compared with ENEA tables for the location and optimum tilt angle (Forli 33°).

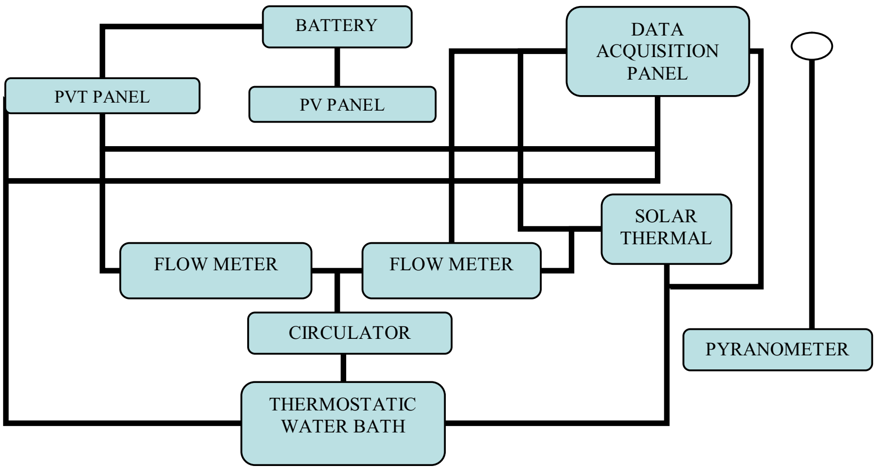


Fig.2 Simplified Hydraulic Scheme

3.Experimental results

In this paragraph table and graphs show some results from thermal and electrical experimental analysis for the comparison of PVT with separated ST and PV panels. The structure is located in a university lab in Forlì, in the North East of Italy close to the Adriatic Sea. The principal goal of our analysis was to analyze respectively instantaneous thermal efficiency η_t, open circuit voltage V_{oc} , increasing or decreasing ΔT_{in_out} and ΔV_{oc} percentage panels' values. Subsequently also maximum power point mode (MPP) electrical analysis has been included. AC/DC voltage and current values present a measurement uncertainty of +/- 0.5% and +/-1% respectively. The overall thermal efficiency uncertainty is less than 6% .Results from the latest most significance test days, including also optimum fluid flow rate analysis, are under shown.

Table 1.Test day

Date	Hour	T_{mI} [°C]	T_{mT}[°C]	q_I[°C]	q_T[°C]	η_I	η_T
16/07/2012	16:53	17,51	17,57	121,03	139,09	50,96%	58,57%
16/07/2012	17.00	18,96	19,04	132,92	158,80	58,11%	69,42%
16/07/2012	17:07	20,19	20,22	115,87	125,52	51,50%	55,79%
16/07/2012	17:16	21,64	21,73	135,45	164,34	62,28%	75,56%

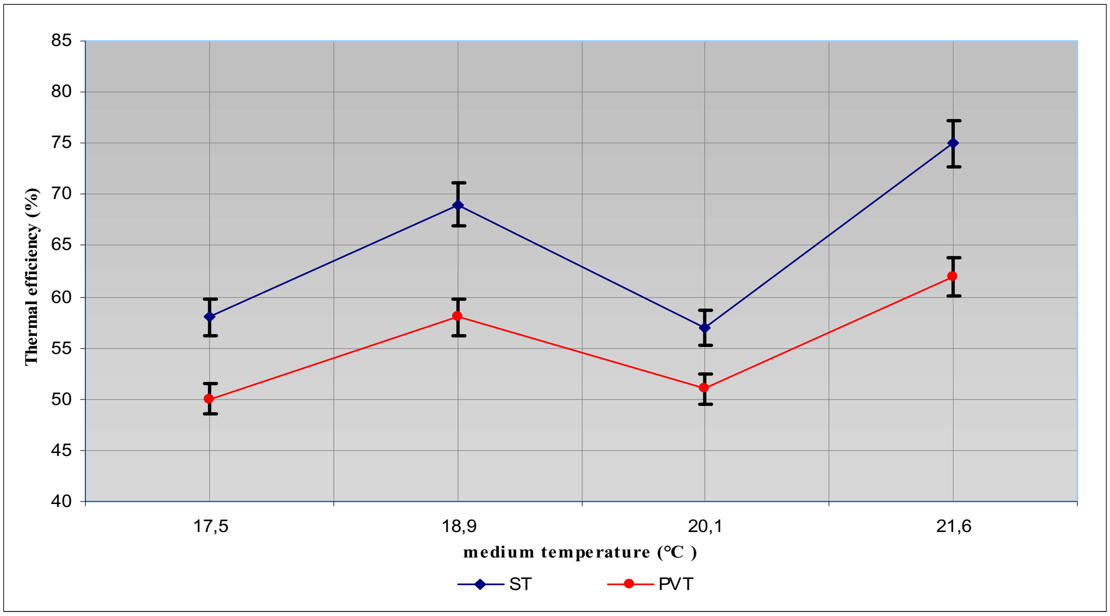


Fig.3. Thermal Efficiency ST (-) Vs PVT (-)

From Fig.3 we can see how outdoor operating conditions are quickly changing during a standard test day (clear sky covered by clouds.etc...) determining a decreasing thermal efficiency for both the panels (lower percentage difference).

Table 2.Summary test results

Date	Hour	I[W/m^2]	Q[l/min]	[m^3/s]	T_i[°C]	T_{oI}[°C]	T_{oT}[°C]	T_{mI}[°C]	T_{mT}[°C]	q_I[W]	q_T[W]	η_I	η_T
16/07/12	16:59	915	1,89	0,000031	18,36	19,23	19,38	18,80	18,87	115,16	134,76	50,34%	58,91%
16/07/12	17:00	915	2,32	0,000039	18,55	19,37	19,53	18,96	19,04	132,92	158,80	58,11%	69,42%
16/07/12	17:01	915	2,51	0,000042	18,71	19,44	19,59	19,08	19,15	127,57	152,67	55,77%	66,74%
17/07/12	16:09	1060	1,90	0,000032	18,76	19,74	19,91	19,25	19,34	129,98	152,20	49,05%	57,44%
17/07/12	16:10	1060	2,33	0,000039	18,98	19,90	20,14	19,47	19,56	158,30	188,52	59,74%	71,14%
17/07/12	16:11	1060	2,52	0,000042	19,29	20,15	20,31	19,72	19,80	150,73	178,85	56,88%	67,49%
18/07/12	12:24	975	1,87	0,000031	18,49	19,37	19,63	18,93	19,06	114,85	148,84	47,12%	61,06%
18/07/12	12:25	975	2,31	0,000039	18,67	19,55	19,79	19,11	19,23	140,30	179,60	57,56%	73,68%
18/07/12	12:26	975	2,50	0,000042	18,98	19,72	19,94	19,35	19,46	128,45	166,81	52,70%	68,44%
25/07/12	12.12	875	1,80	0,000030	19,36	20,17	20,37	19,76	19,87	101,39	126,78	46,35%	57,98%
25/07/12	12:14	875	2,29	0,000038	19,63	20,43	20,61	20,03	20,12	127,77	155,24	58,41%	70.97%
25/07/12	12:15	875	2,49	0,000041	19,98	20,62	20,78	20,30	20,38	112,27	138,63	51,32%	63,37%
27/07/12	16:35	920	1,83	0,000031	19,09	19,85	20,18	19,47	19,63	96,87	138,98	42,12%	60,43%
27/07/12	16:36	920	2,29	0,000038	19,27	20,02	20,36	19,64	19,81	120,01	174,35	52,18%	75,80%
27/07/12	16:37	920	2,47	0,000041	19,54	20,17	20,48	19,86	20,01	107,24	160,82	46,63%	69,92%

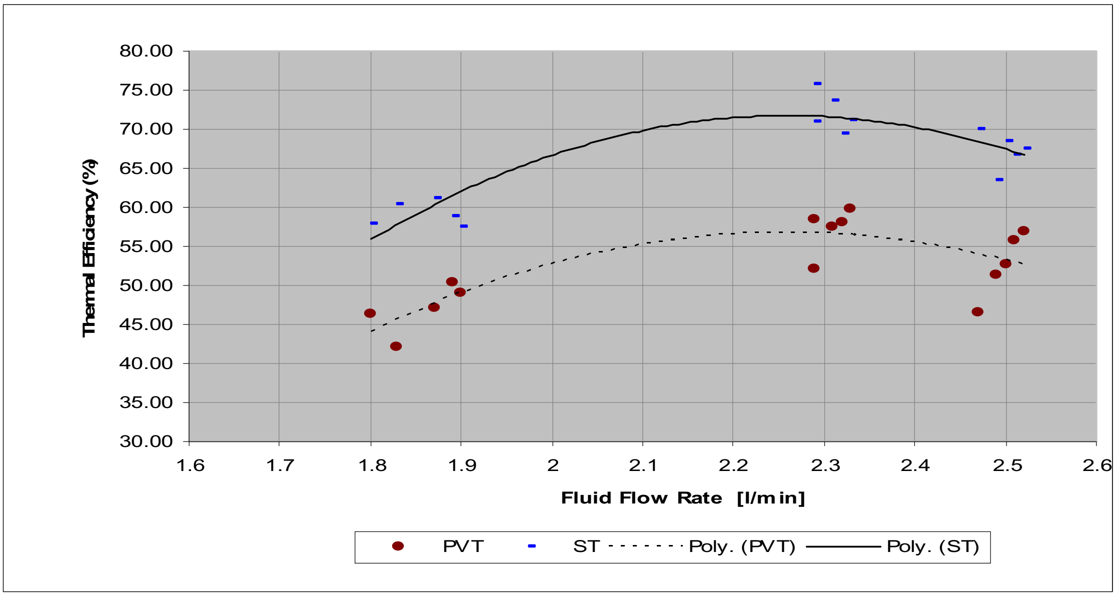
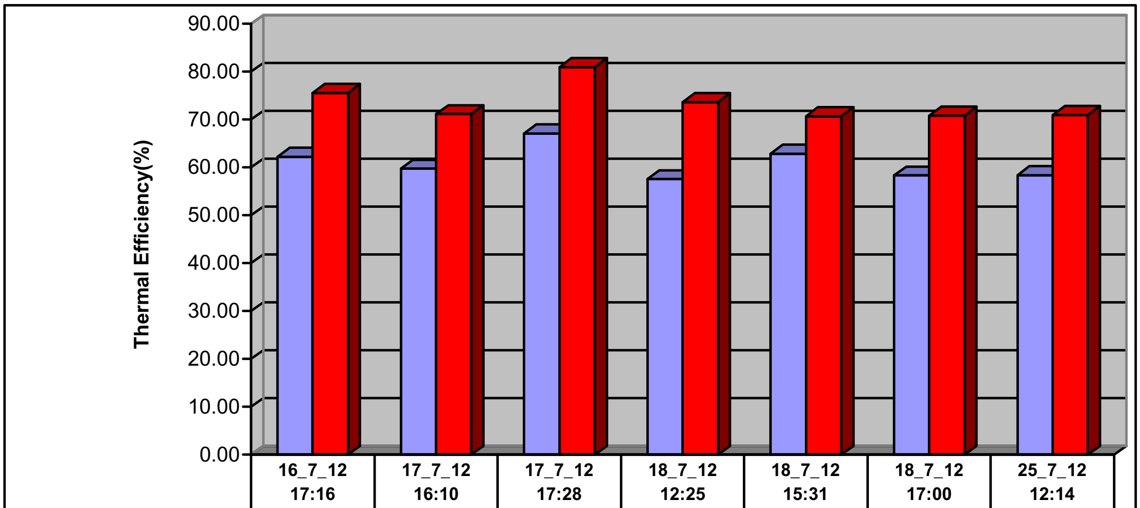


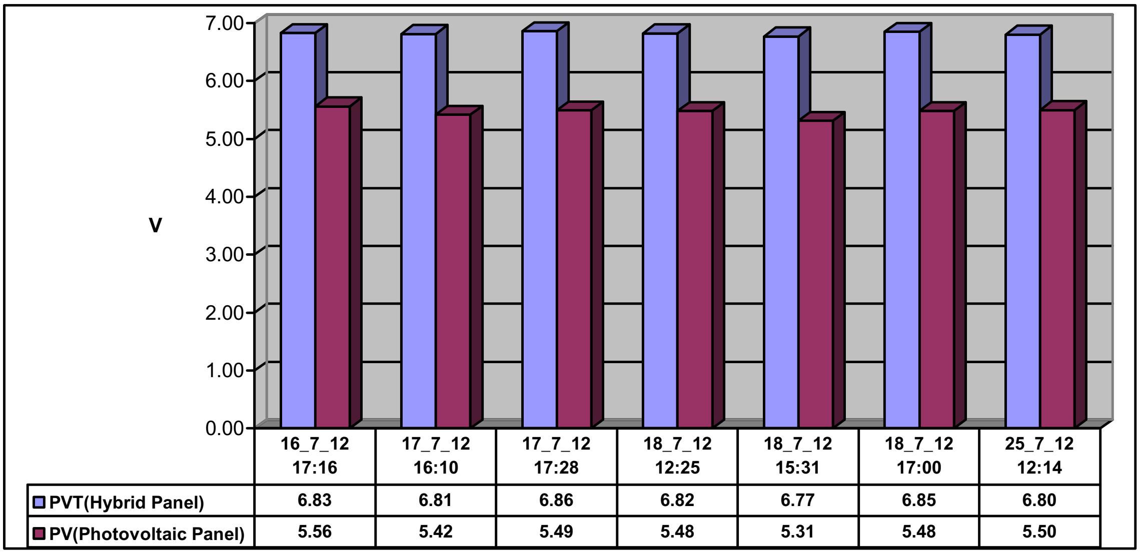
Fig.4. Thermal Efficiency ST (-) _ PVT (-) Vs Fluid Flow

The upper graph (Fig.4) shows, under the values tested on our experimental analysis (1,85, 2,33 and 2,55 l/min) , the corresponding thermal performance. The best value to be chosen in this range is near 2,33 l/min (underlined by polynomial trend curves).



	16_7_12 17:16	17_7_12 16:10	17_7_12 17:28	18_7_12 12:25	18_7_12 15:31	18_7_12 17:00	25_7_12 12:14
PVT(Hybrid Panel)	62.28	59.74	67.07	57.56	62.93	58.34	58.41
ST(SolarThermal Panel)	75.56	71.14	80.99	73.68	70.74	70.80	70.97

Fig.5. PVT (-) Vs ST (-) Thermal Efficiency

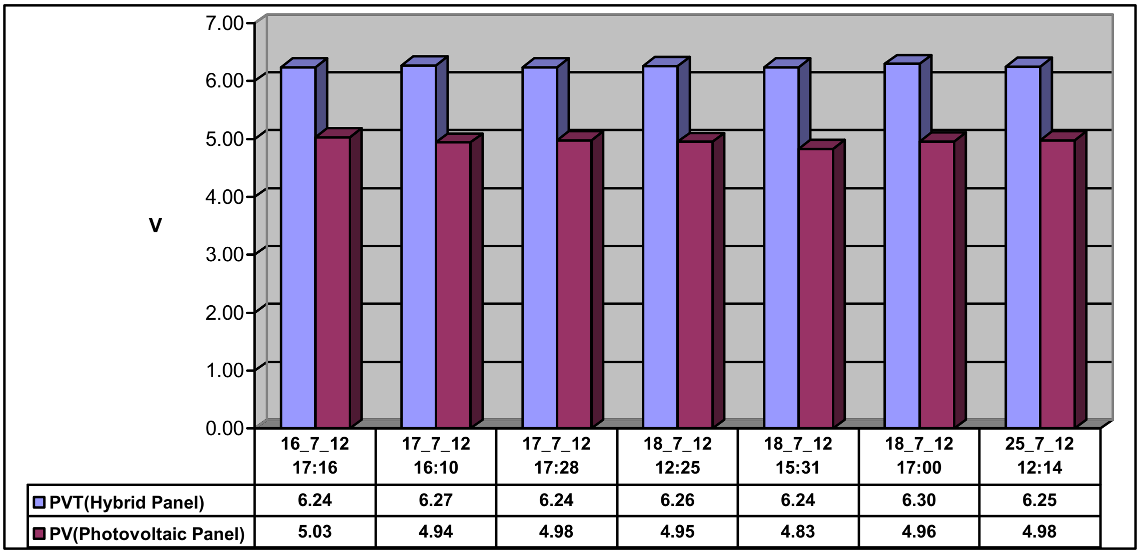


	16_7_12 17:16	17_7_12 16:10	17_7_12 17:28	18_7_12 12:25	18_7_12 15:31	18_7_12 17:00	25_7_12 12:14
PVT(Hybrid Panel)	6.83	6.81	6.86	6.82	6.77	6.85	6.80
PV(Photovoltaic Panel)	5.56	5.42	5.49	5.48	5.31	5.48	5.50

Fig.6a. PVT (-) Vs PV (-) Open Circuit Voltage

Fig.5 and Fig.6a show last thermal and electrical efficiency comparison between PVT and separated panels (ST and PV ones). Graphs underline the same advantages obtained and tested previously with an increasing electric output over the year and a lower thermal performance depending on the season.

In the last graph (Fig.6b) also maximum power point mode (MPP) analysis is added, which confirms increasing electrical values with the same percentage increase (+20-30%).



	16_7_12 17:16	17_7_12 16:10	17_7_12 17:28	18_7_12 12:25	18_7_12 15:31	18_7_12 17:00	25_7_12 12:14
PVT(Hybrid Panel)	6.24	6.27	6.24	6.26	6.24	6.30	6.25
PV(Photovoltaic Panel)	5.03	4.94	4.98	4.95	4.83	4.96	4.98

Fig.6b. PVT (-) Vs PV (-) Maximum Power Point Mode Voltage (MPP)

4.Conclusions

The second phase of outdoor tests, adding also power point mode (MPP) analysis regarding electric performance, has shown and confirmed clear advantages given from the use of this hybrid technology for both the electrical and thermal output .

As for the previous works' results, are confirmed an increasing open circuit voltage (from+15% till +30% depending on different seasons operating conditions) with a little decrease of thermal efficiency (-10/15%) by the single hybrid PVT water panel compared to separated productions.

Concerning power point mode analysis (MPP), results confirm increasing percentage voltage value (+20-30%) despite the lower maximum value obtained due to the electrical conversion.The analysis of the optimum fluid flow rate for the panel has fixed the best thermal efficiency value near 2,33 l/min.

The specific tests on vehicles and boat applications are going to investigate the best design heat sink construction for these applications studied in our research.

At last prototype judging will be completed by the economical analysis of the peak watt cost.

In order to predict the price of this hybrid prototypes for large-scale commercialization, it's necessary to fix the costs of all the equipment and systems (balance of system) necessary for the proper operation of the plant
(mounting brackets, inverters, charge controllers, fuel tanks, hydraulic and electrical devices).

References

[1]Fabbri G, Greppi M, Lorenzini M. *PVT water based prototype construction and experimental efficiency analysis for a particular italian north-east location*. Proceedings of 30th Heat Transfer Conference-UIT, BOLOGNA, Esculapio, 2012, 301-306.

[2]Fabbri G, Greppi M, Lorenzini M. *Optimization with genetic algorithms of PVT system global efficiency*. «JOURNAL OF ENERGY AND POWER ENGINEERING», 2012, 6, pp. 1035 – 1041.

[3]Smith C, Weiss A. *Design application of the Hottel-Whillier-Bliss equation*.Solar Energy (1977) Vol.19Isuue.2,109-113.

[4]Boer K.W. *Solar retrofitting of existing residence with almost zero-delta Te system*. ISES New Dehli, (1978).

[5]Tiwari A, Sodha M. *Performance evaluation of hybrid PVT water/air heating system:A parametric study.* RenewableEnergy,(2006),31,2460-2474.

[6]Zondag,H.A., de Vries DW, van Helden WGJ, vanZolengen RJC, Steenhoven AA. *The yield of different combined PV-thermal collector designs*. Solar Energy(2003);74(3),253-269.

[7]Dupeyrat P, Kwiatkowski G, Menezo C, Rommel M., Stry-Hipp G. *Experimental and numerical assessment of PVT collector for combined production of electricity and domestic hot water.* project PVTCOL "- 2011.

[8]Polman A, Harry A. Atwater *Photonic design principles for ultrahigh-efficiency photovoltaics* Nature Materials 11,174–177(2012).

[9]ISO (1994) 9806-1: *Test methods for Solar collectors. Part 1: Thermal performance of Liquid heating collectors*, ISO, Switzerland.